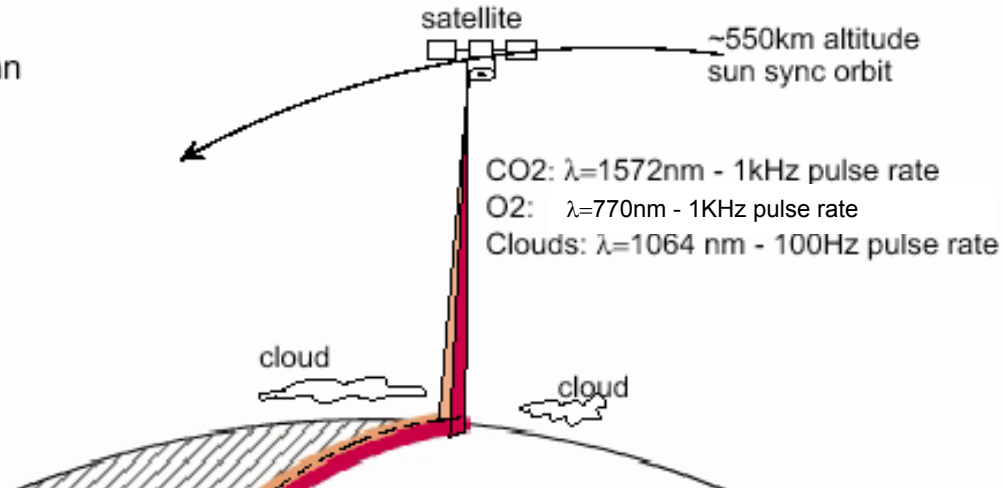
Laser Sounder
for Remotely Measuring Atmospheric CO_2 Concentrations

Measures:
- CO2 tropospheric column
- O2 tropospheric column
- Cloud height profile



Earth Science Technology Conference

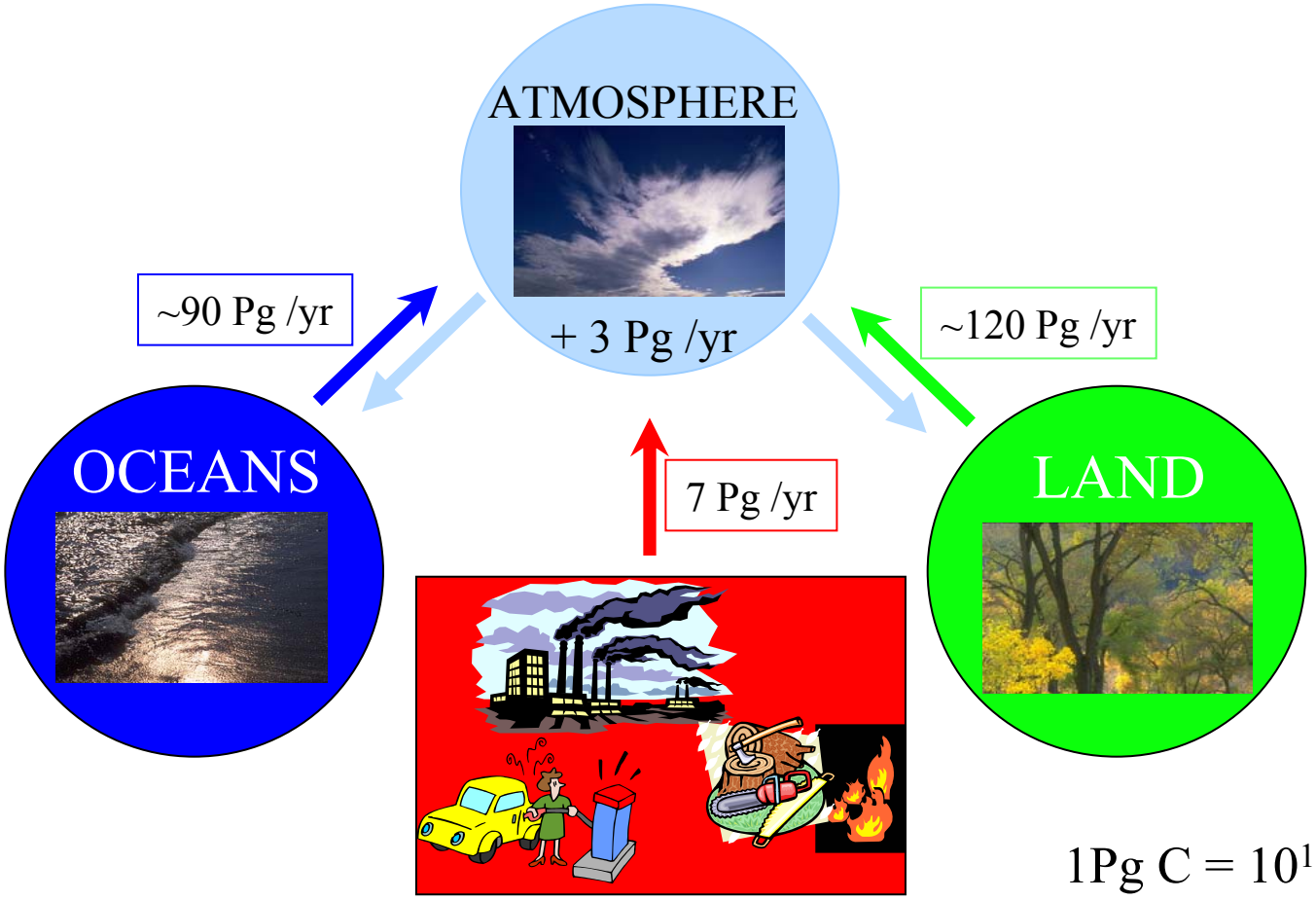
James Abshire, Michael Krainak, Xiaoli Sun, Haris Riris,
Arlyn E. Andrews, John Burris, Mark Stephen, G. James Collatz

06/24/03

Supported by:

ESTO ACT program, GSFC IR&D funding

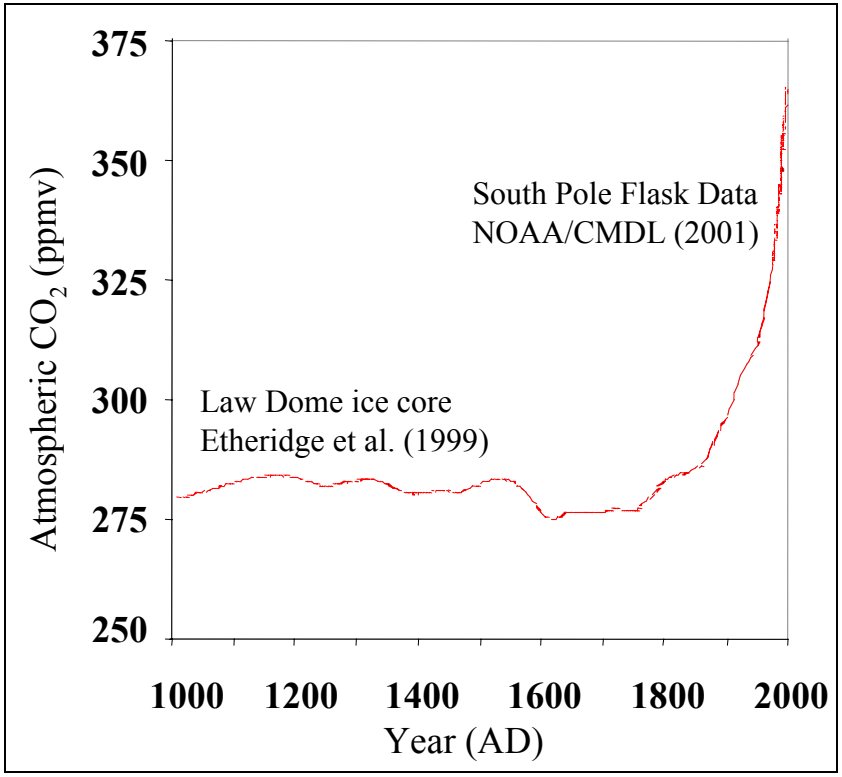
The Global Carbon Cycle



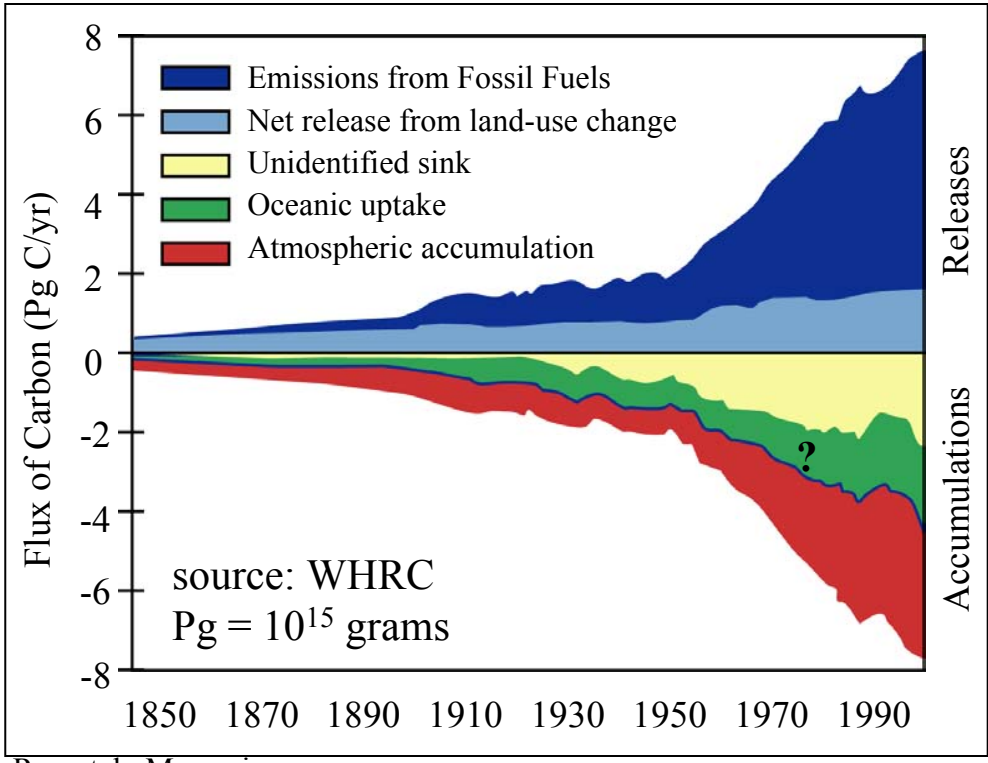
$1 Pg\ C = 10^{15} g\ C$

- Only about 50% of the CO_2 emitted each year shows up in the atmosphere. The rest is absorbed by ocean or terrestrial "sinks".
- A detailed understanding of these sinks is needed to predict future atmospheric CO_2 levels.

Atmospheric CO2 - history

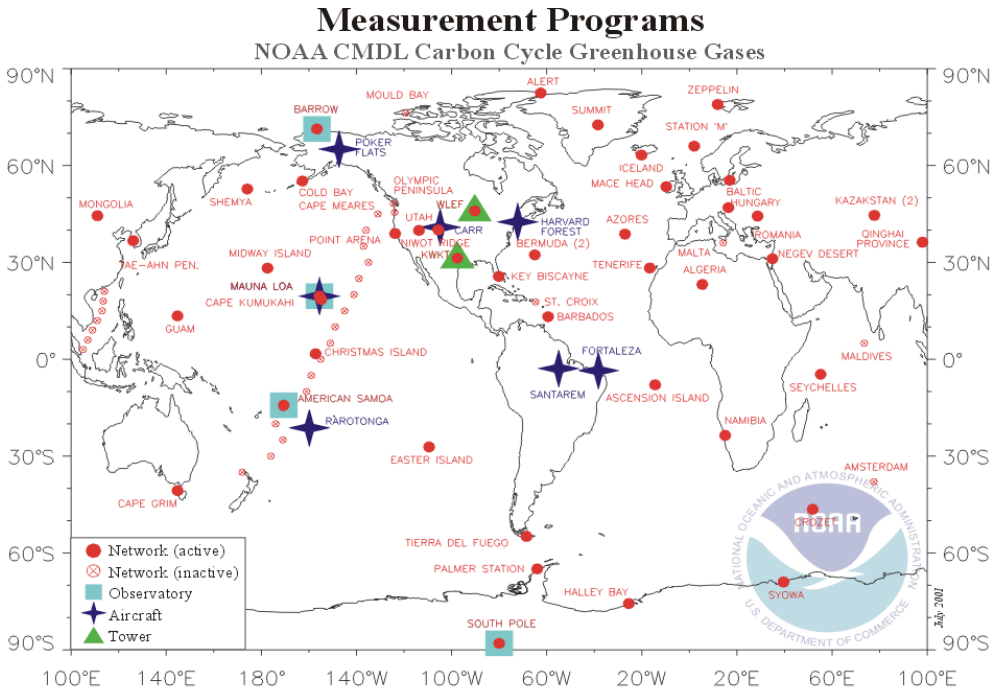


- **Of the anthropogenic CO_2 that has been emitted to date, about 1/3 can not be accounted.**
- **The "unknown sink" may be Northern Hemisphere forests.**
- **Will this unknown sink continue to operate in the future?**



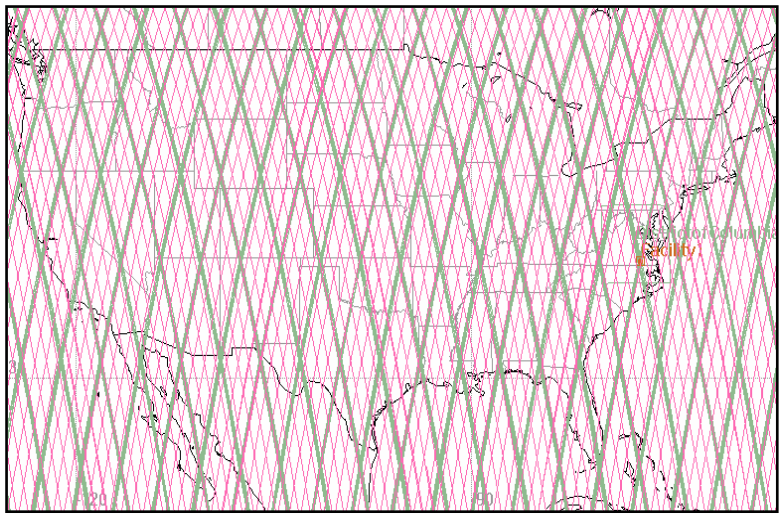
Atmospheric CO_2 is higher today than at any time in the past 400,000 years.

CO_2 Global Sampling
Current Capability vs. Laser Sounder Potential Coverage



NOAA/CMDL
Surface Air Sampling Network

Ground Track Over USA



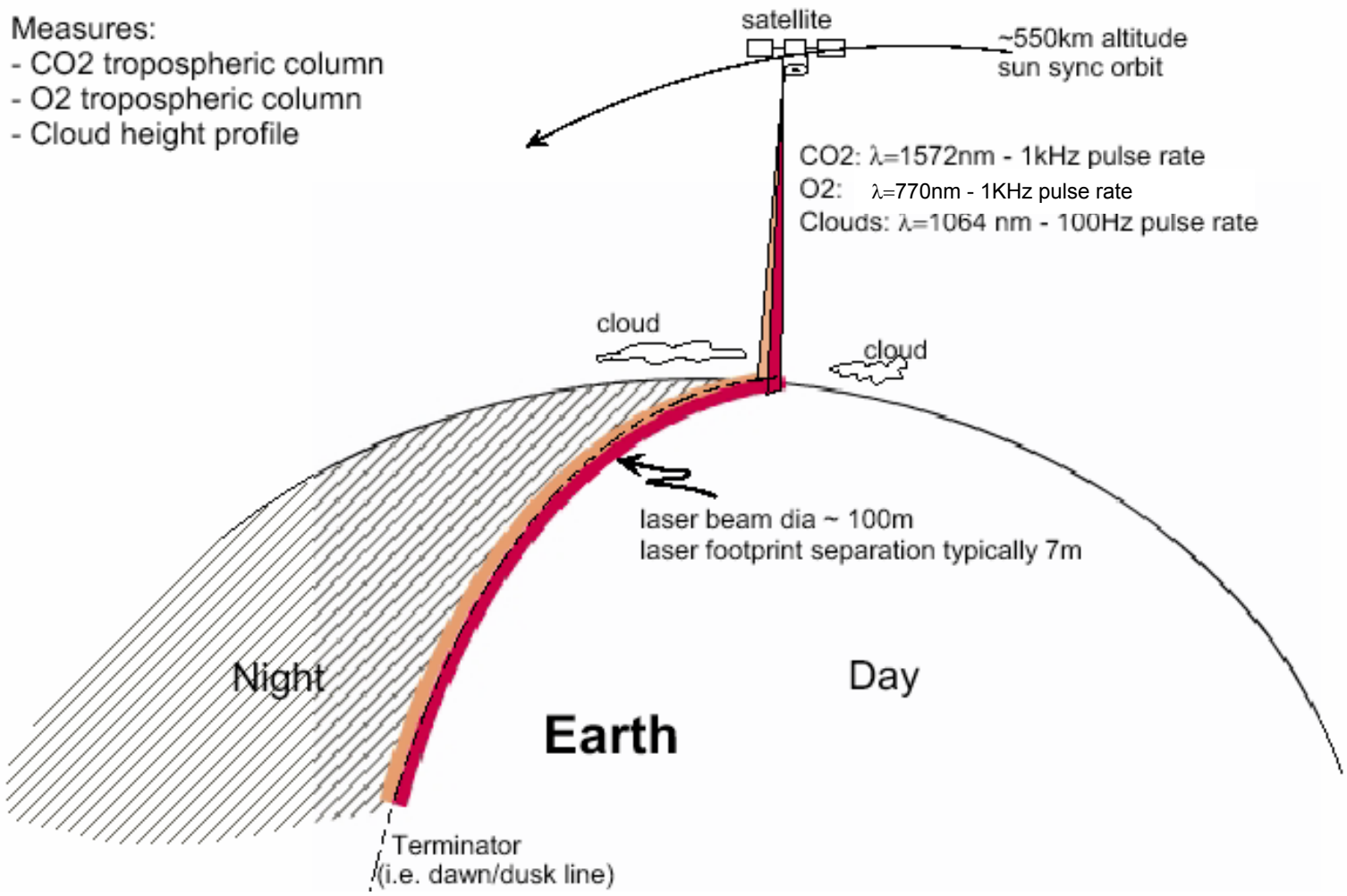
Orbital Laser Sounder

Advantages

- **global coverage**
- **column abundances & vertical resolution**
- **dawn-dusk measurement times.**

Laser Sounder

for Remotely Measuring Atmospheric CO_2 Concentrations

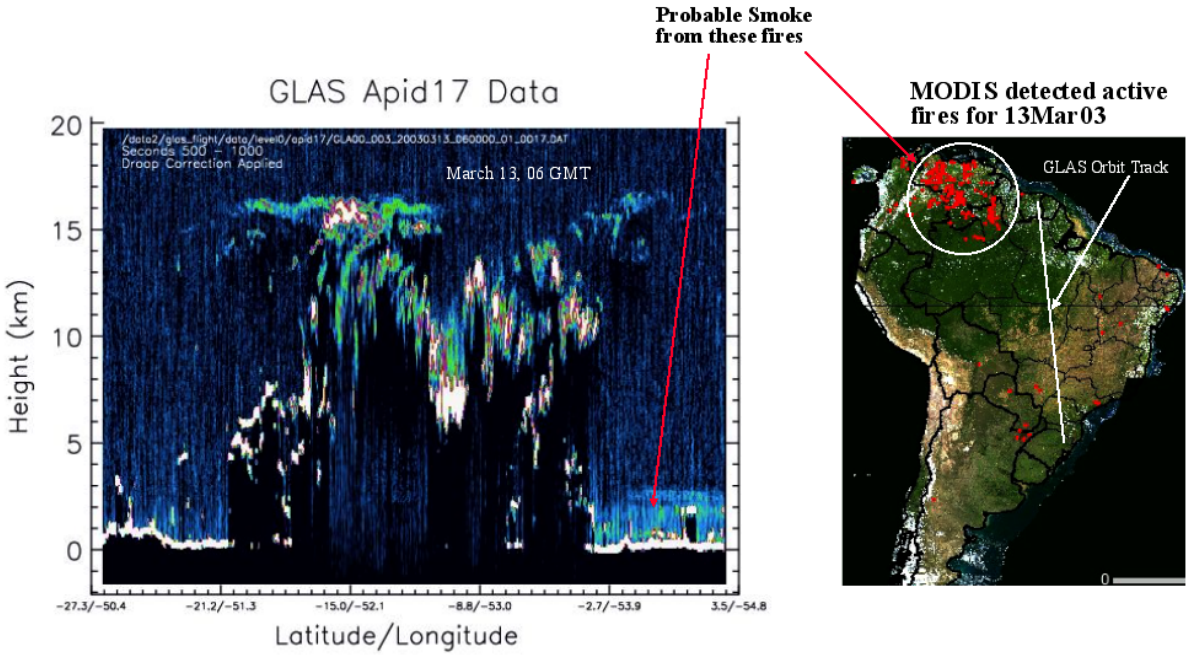


Algorithm Development: Future Directions

- Consider impact of atmospheric H_2O on measurement.
- Detailed calculations to determine impact of clouds and aerosols on retrieved CO_2
- Currently planning for GLAS-like aerosol & cloud channel, but need to define requirements.

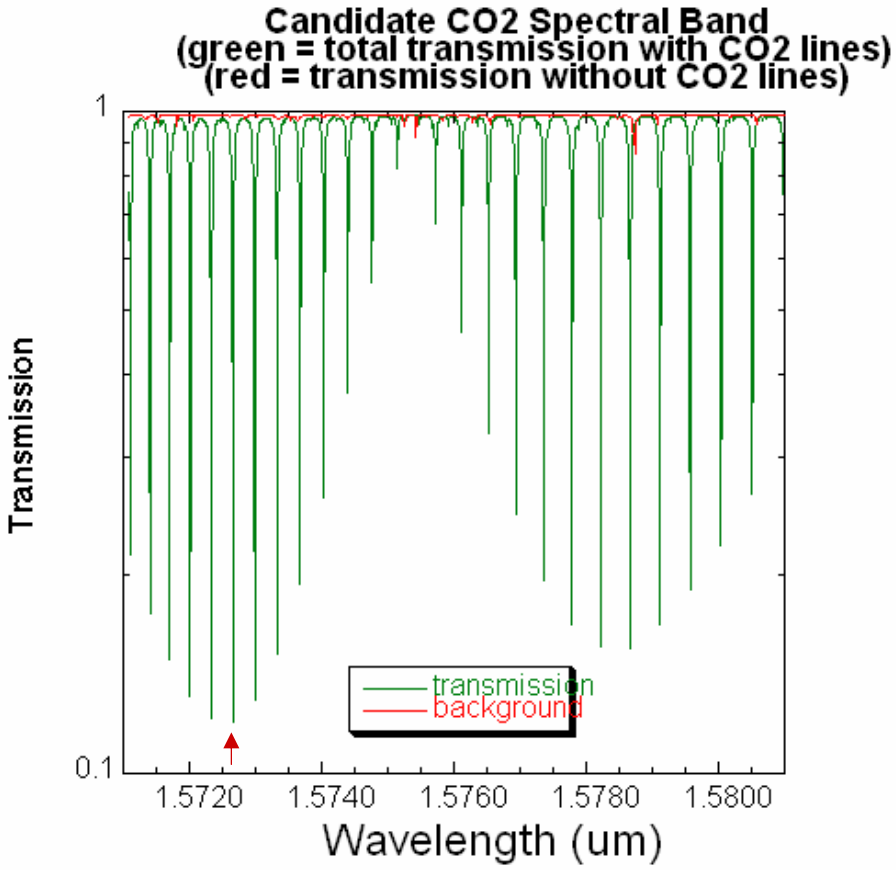
Measurement Examples: Thunderstorm & Smoke from Biomass Burning

- Preliminary data from GLAS illustrates complexity of atmospheric backscatter.
- Is another area where Lidar techniques have a strong advantage over passive measurements.

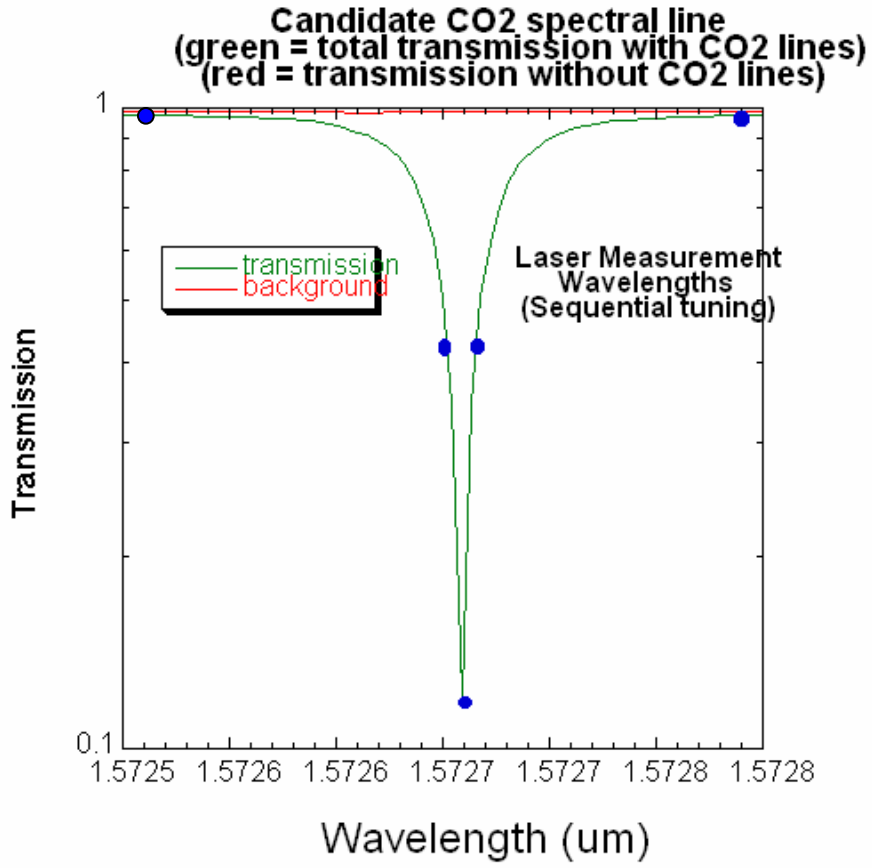


CO2 1570nm Absorption Band

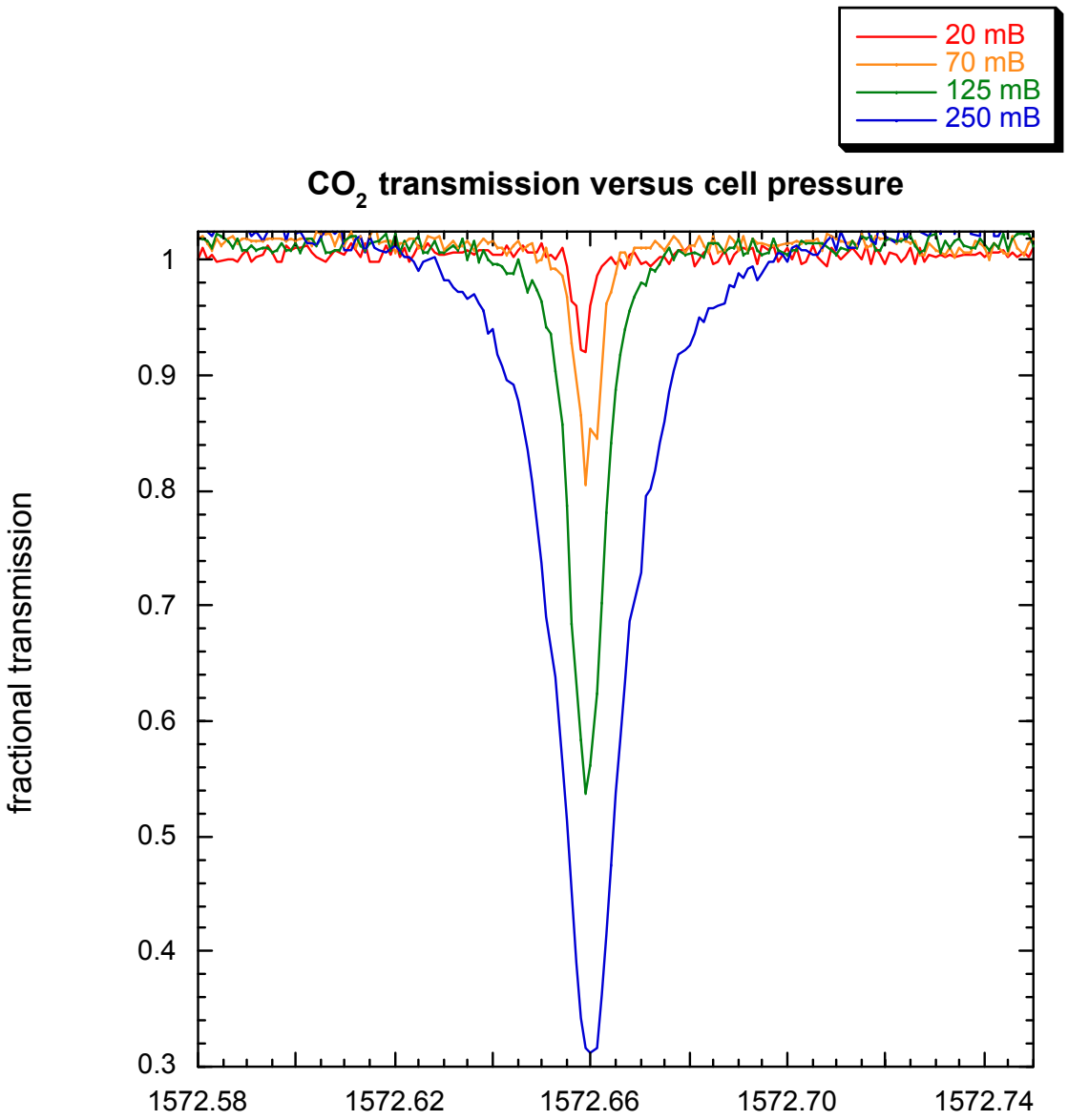
CO2 1570nm Absorption Band



Single CO2 Absorption Line & Background



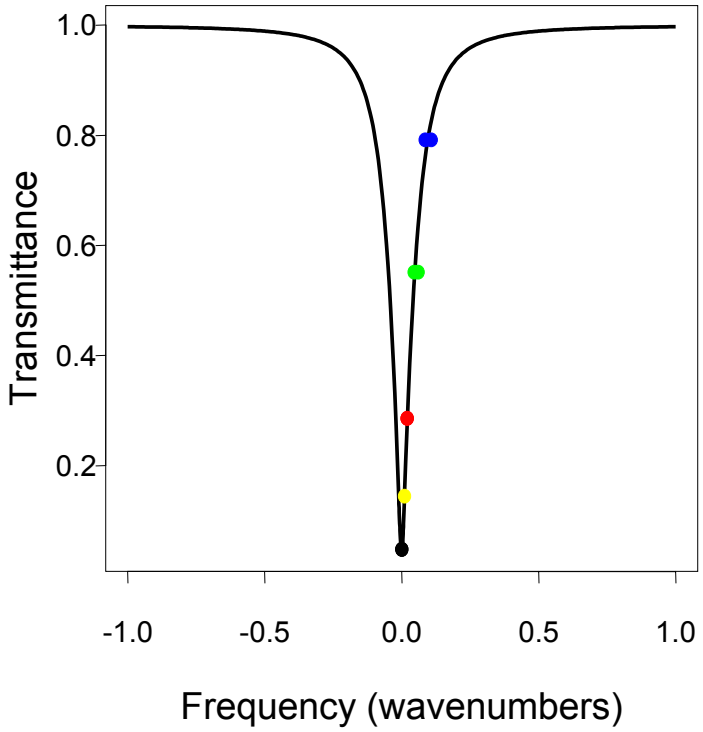
CO2 Absorption Line - Pressure Broadening

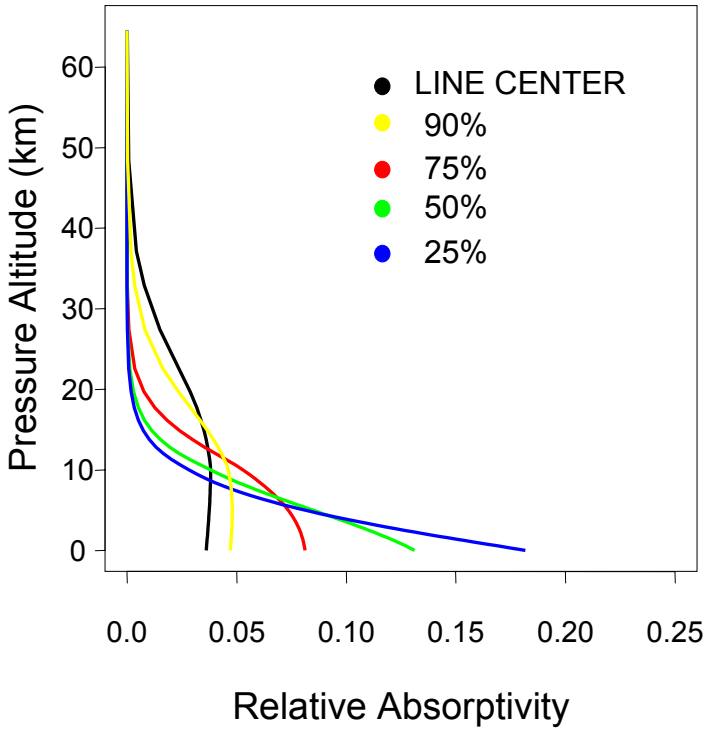


Laser Sounder Total Column Measurement Still Provides Vertical Resolution From CO_2 Line Broadening

Vertical sensitivity as a function of frequency for a line near 1.6 μm:

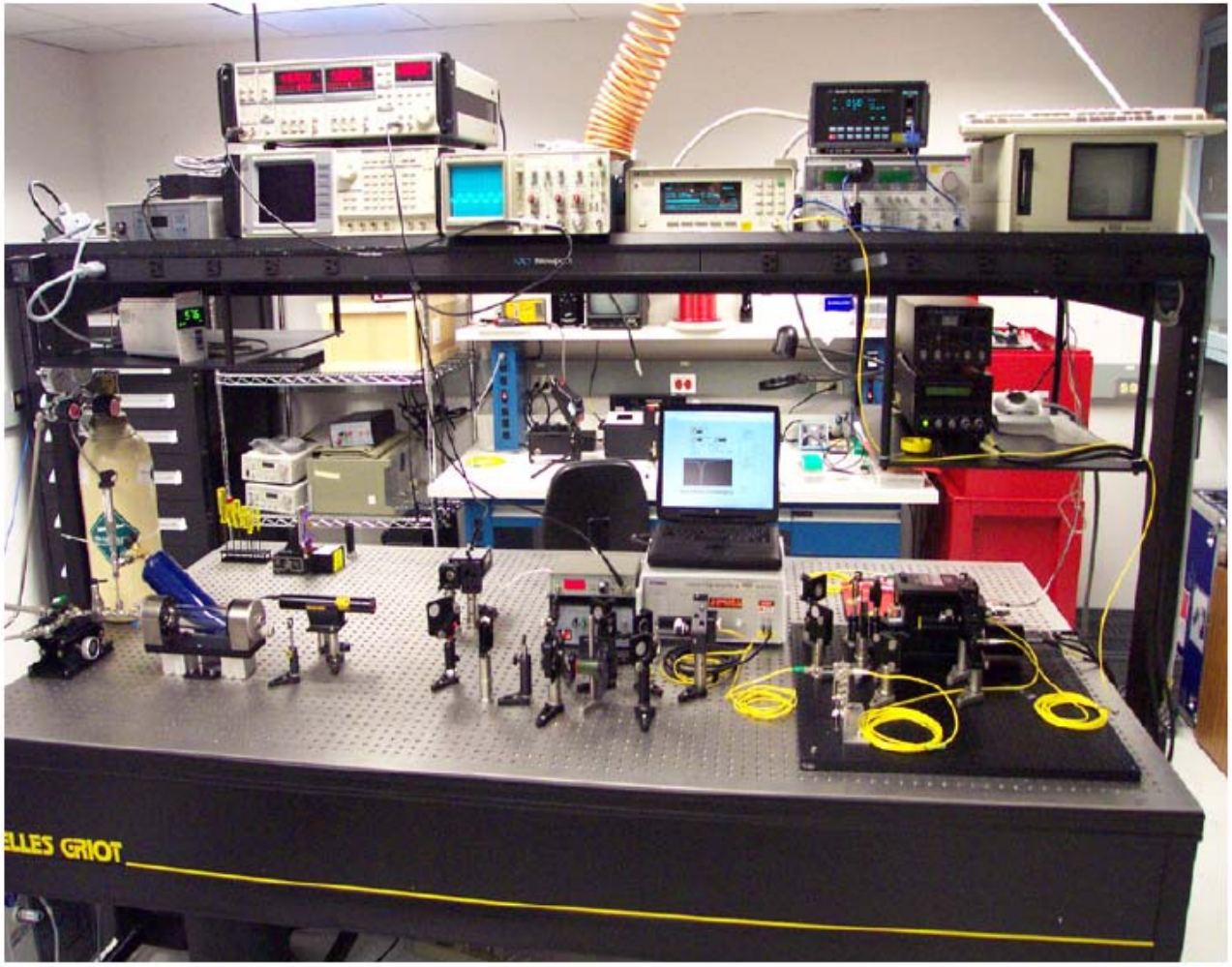
Line centers more sensitive to high-altitudes (Doppler broadening dominates)
Line wings more sensitive to low-altitudes (Pressure broadening dominates)
CO_2 atmospheric concentration is biased to lower altitudes (molecular weight)



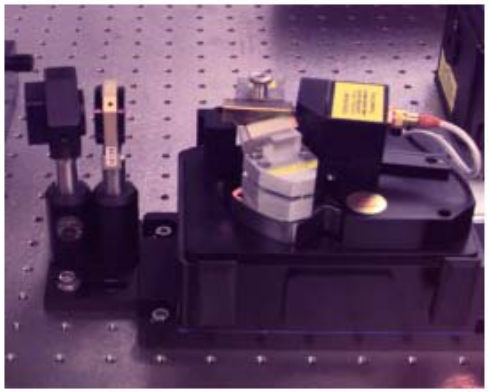


In-situ (Multi-pass Gas Cell) Pure CO_2 Spectroscopy

Experimental Setup



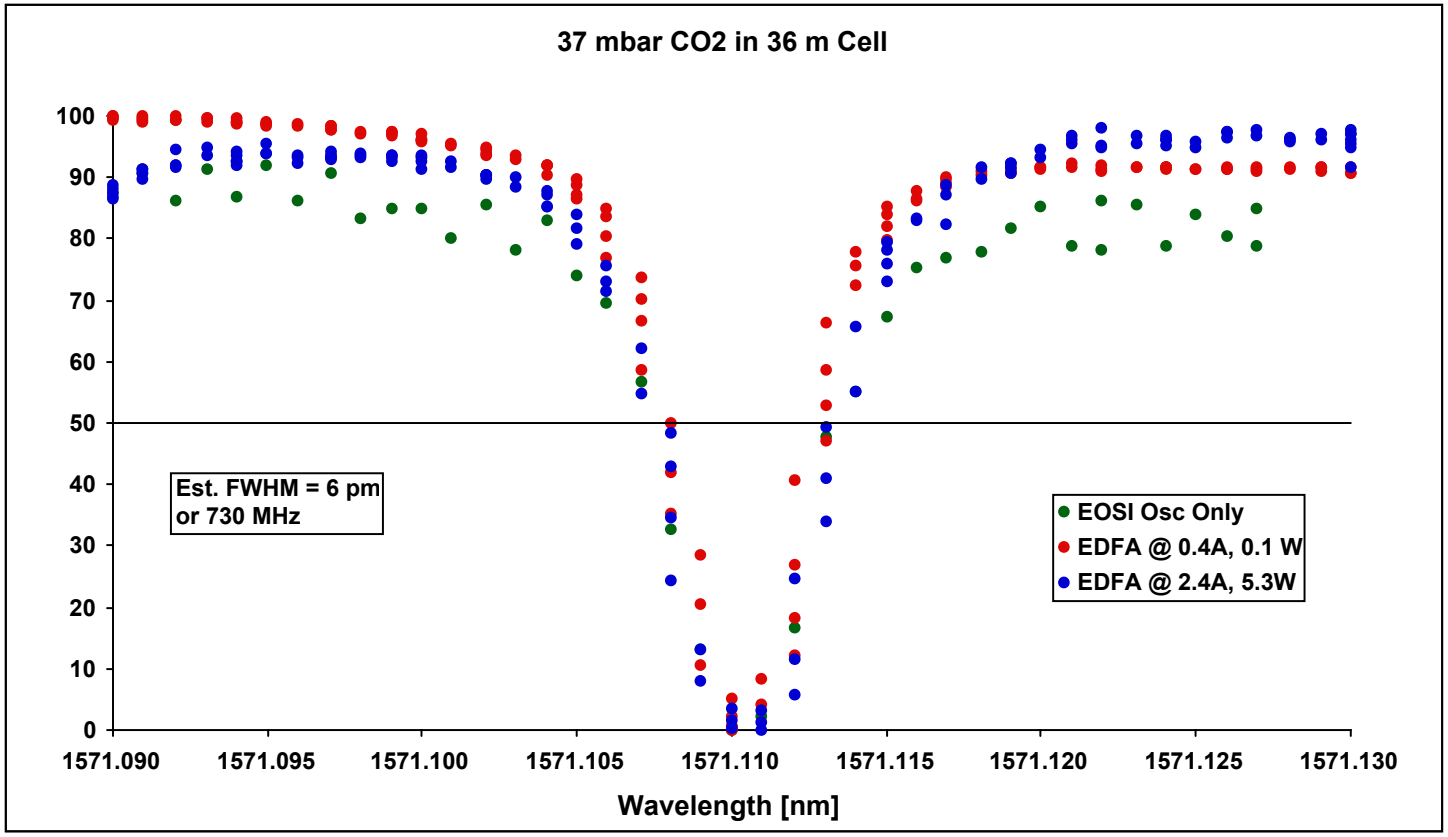
Tunable seed laser



Er-doped Fiber amp

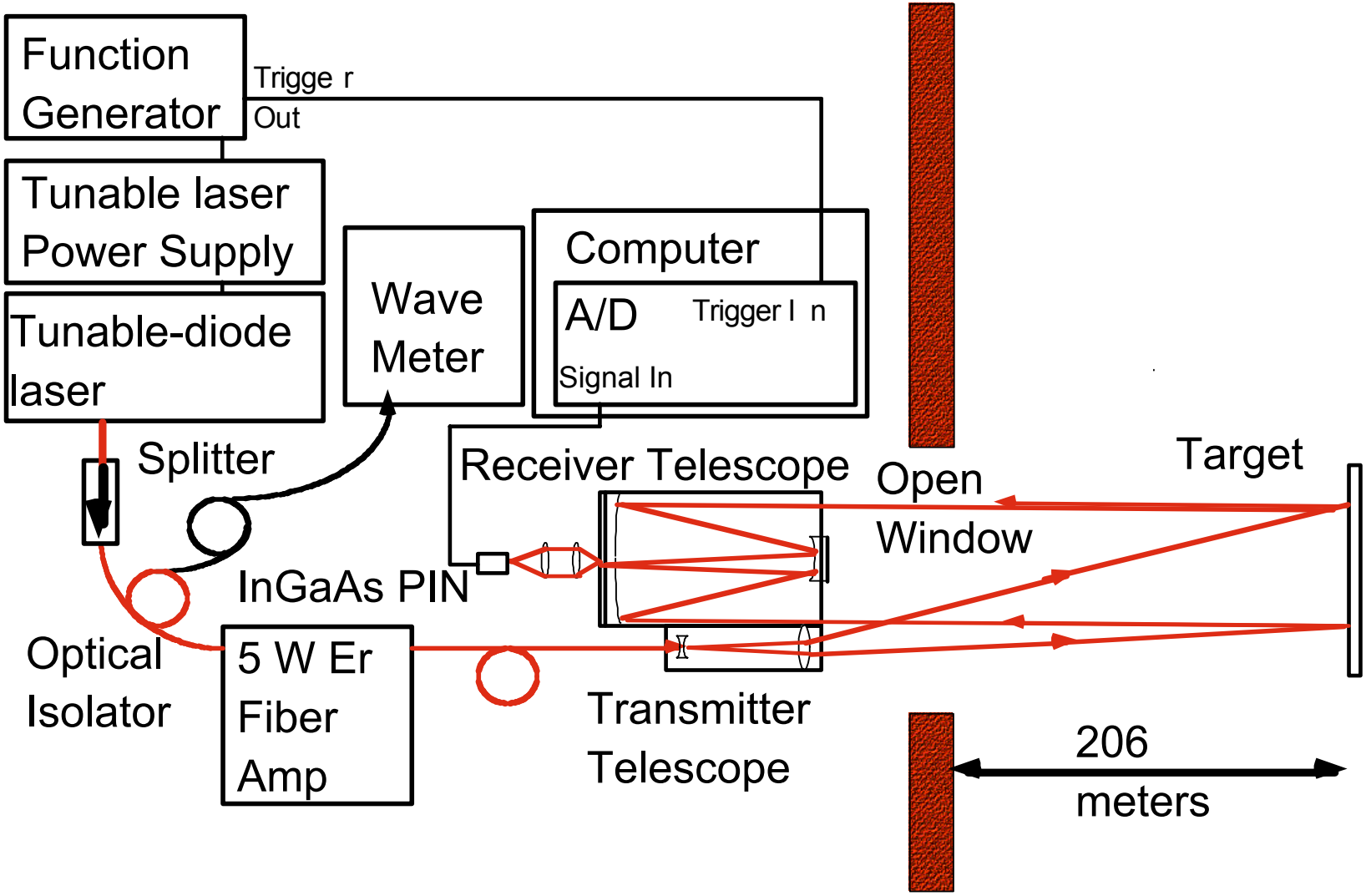
Measured Pure CO_2 Absorption Line Spectra Comparison

Tunable laser diode alone and w/diode amplified by 5W EDFA



No Noticeable Line Broadening from EDFA

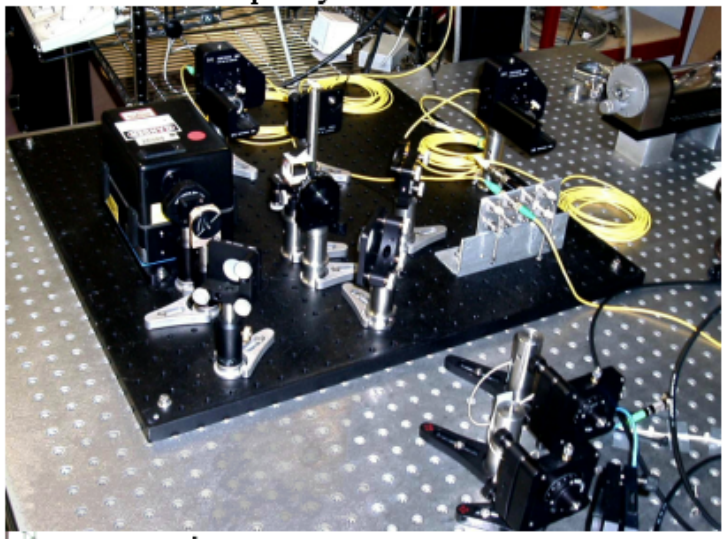
CO2 Sounder Prototype Instrument Diagram



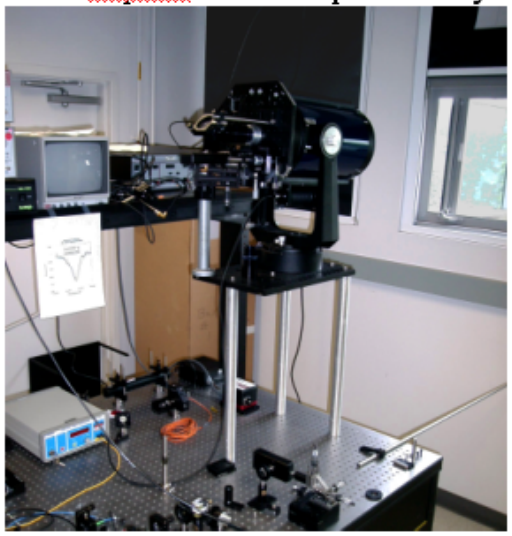
Open Path Atmospheric CO2 Measurement

Test Range (206 m one-way path)

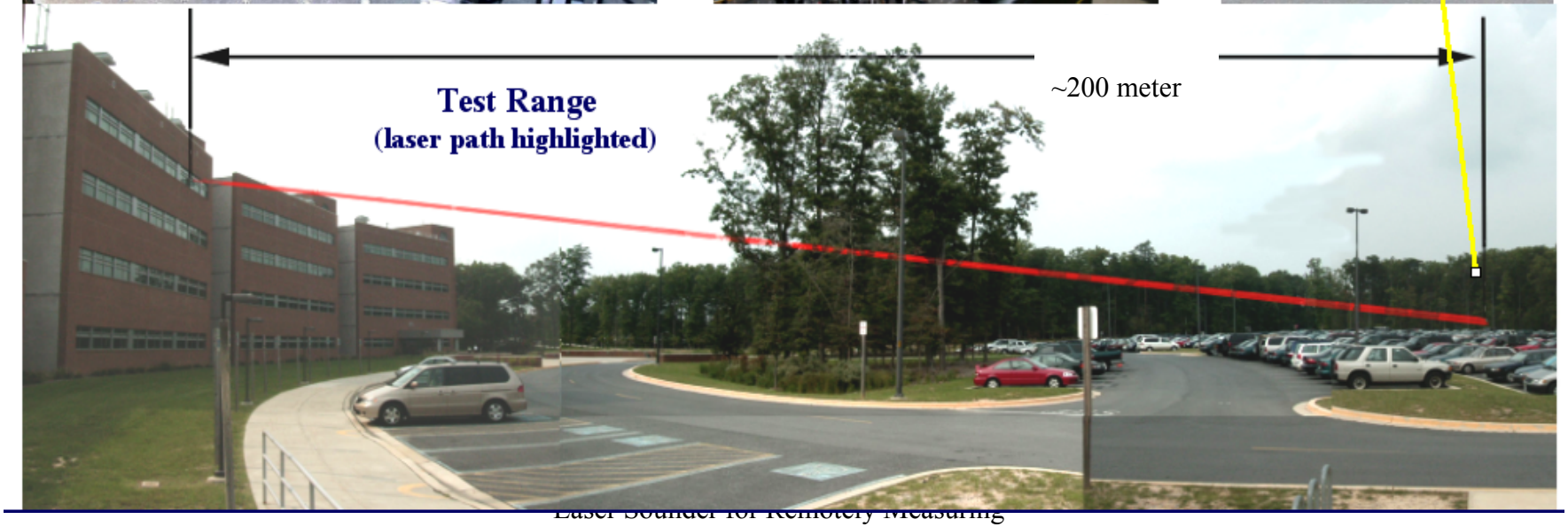
Frequency Tunable diode laser



Fiber amplifer & Telescope assembly



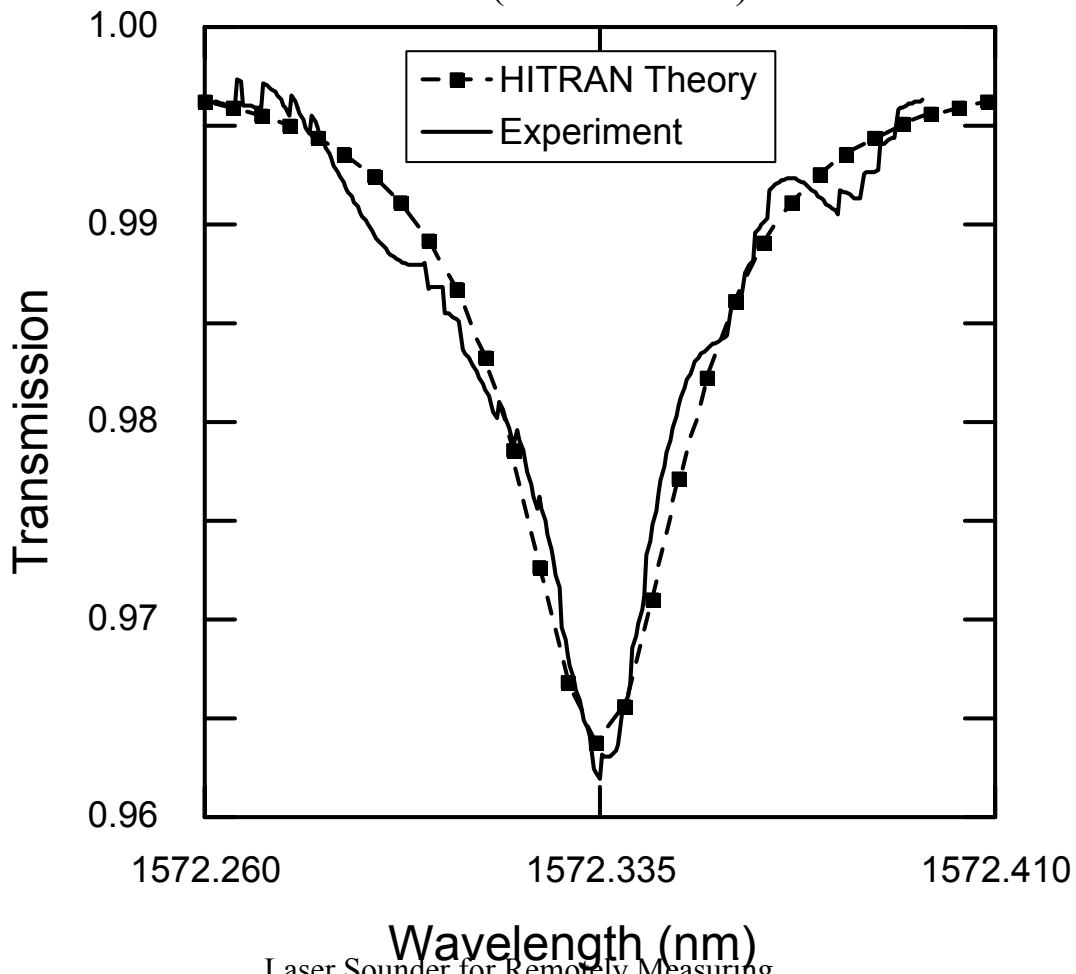
Target (in tree)



FC

Measurement of atmospheric CO2 with Laser Sounder Prototype Instrument

HITRAN theory and measured (N=2000) atmospheric transmission
at NASA Goddard Greenbelt, MD for 206 m one-way path on 11/21/02 at 4:50 PM EST.
(2000 averages - 200 Hz sweep rate - line scanning technique)
One Parameter (Transmission) Fit



Trace Gas Measurement Station (Licor)

Carbon dioxide and Water Vapor

Characteristics:

Gas flow rate: 6.7 standard cc's/sec

Resolution: <0.5 ppm

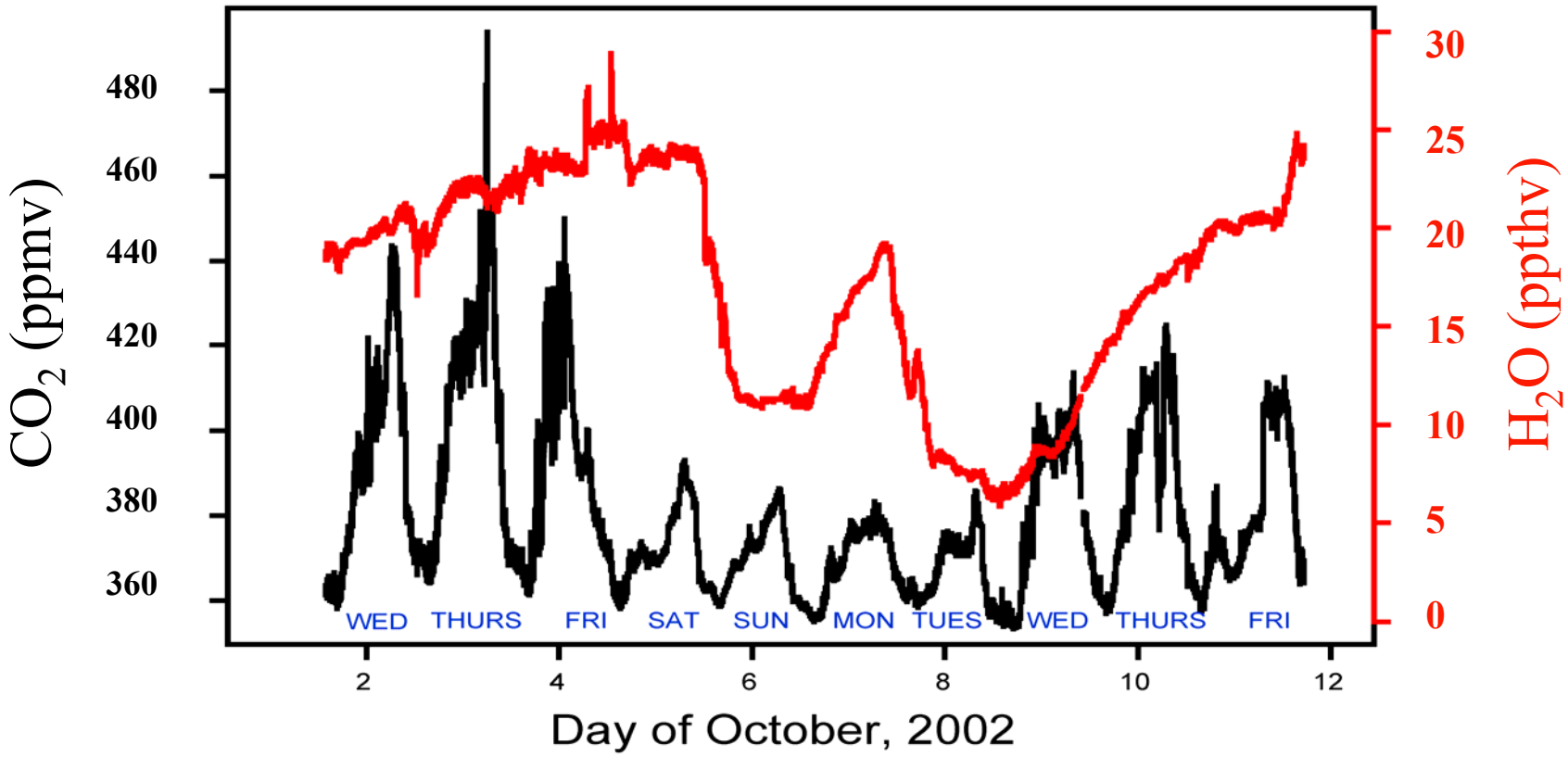
Accuracy: ~ 1 ppm

Sampling rate: 0.1 Hz (10 sec)

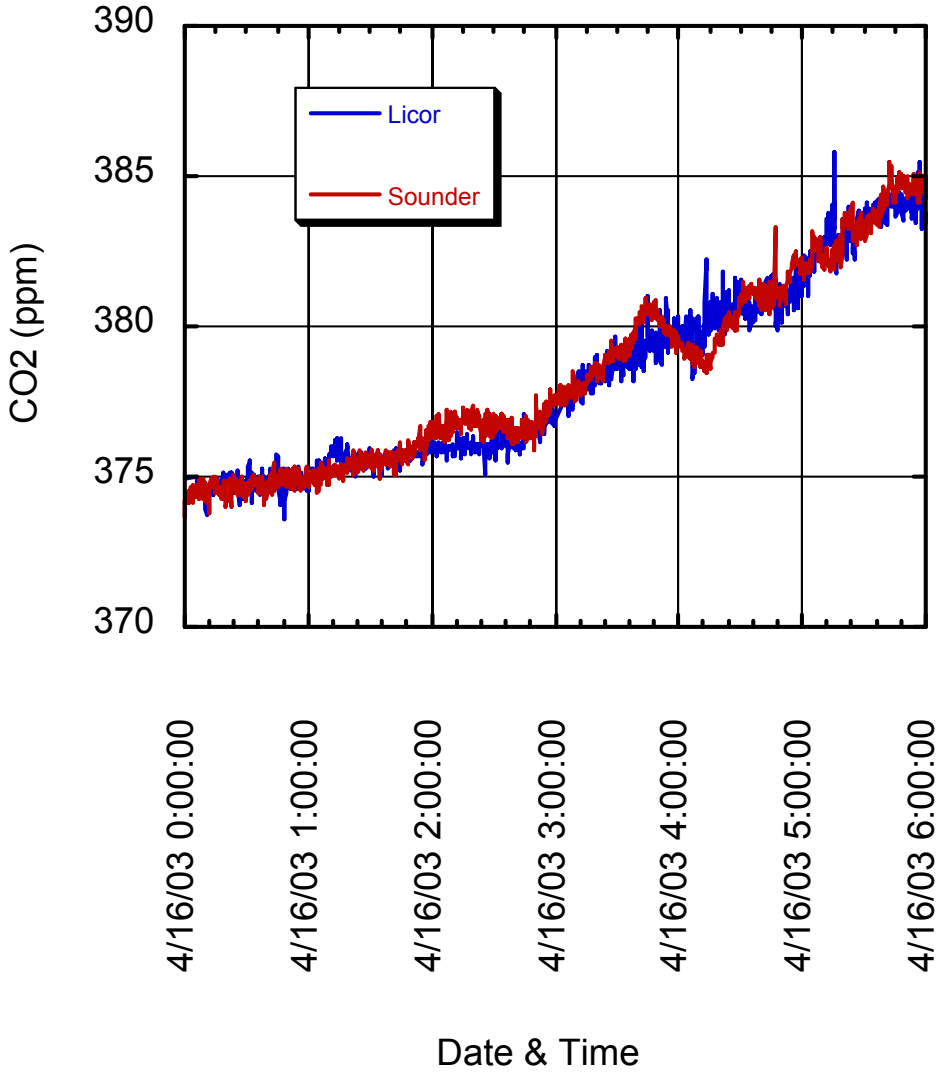
- **Licor operating continuously with automatic calibrations.**
- **Co-located on rooftop with weather station—provides meteorological context (e.g., wind speed, direction) needed to compare Licor data with laser sounder.**

Measured Variation in Atmospheric CO_2

Clearly Evident Diurnal Cycle (Licor Data)



Comparison of Laser Sounder Prototype with Licor instrument Atmospheric CO_2 measurement

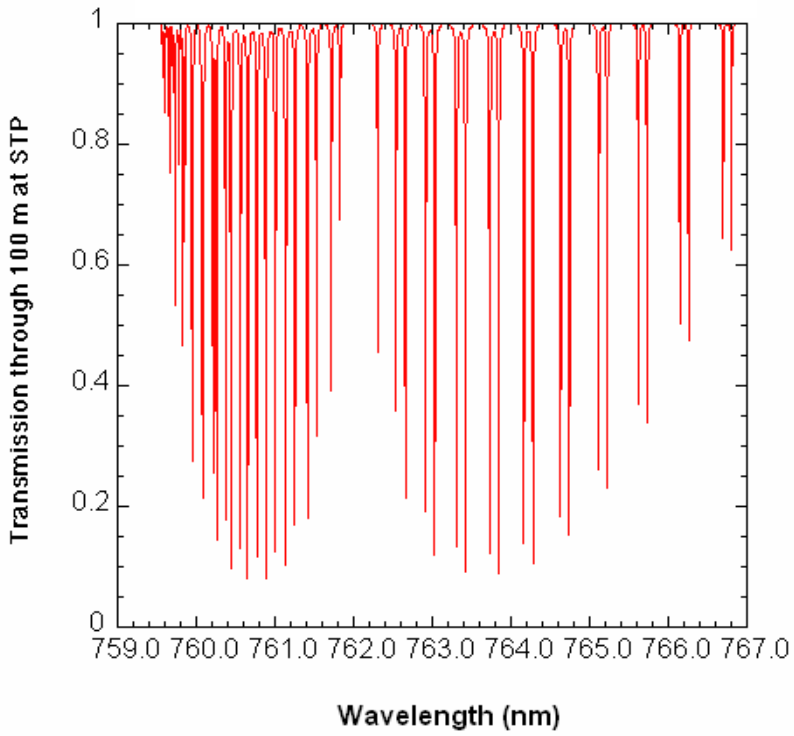


Excellent agreement (correlation) (±1 ppm over 6 hours).

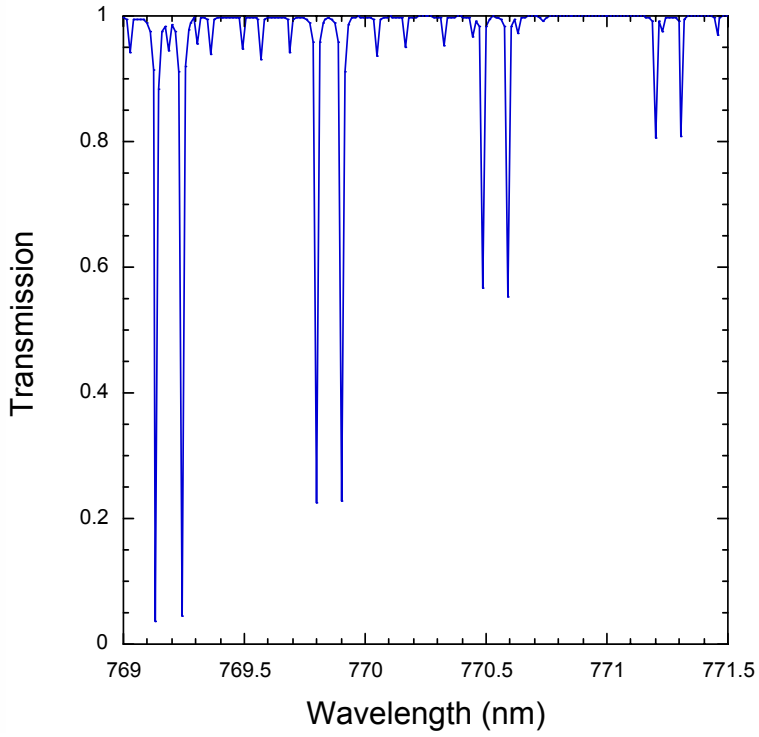
- Sounder raw data offset and scaled
- Sounder referenced to Licor at a single point

O_2 Channel for Laser Sounder

O_2 Band and Lines



HITRAN calculation of absorption in the O_2 A-Band near 761 nm for a horizontal path of 100m at STP.



Calculated ground-space absorption for candidate O_2 lines.

O2 Channel - Frequency Doubling Layout

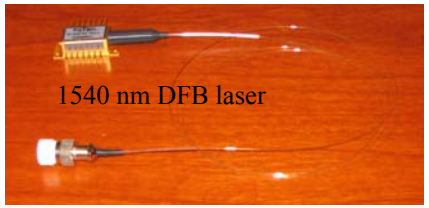
1540/770 nm Single Harmonic Generation (SHG) Experimental Layout

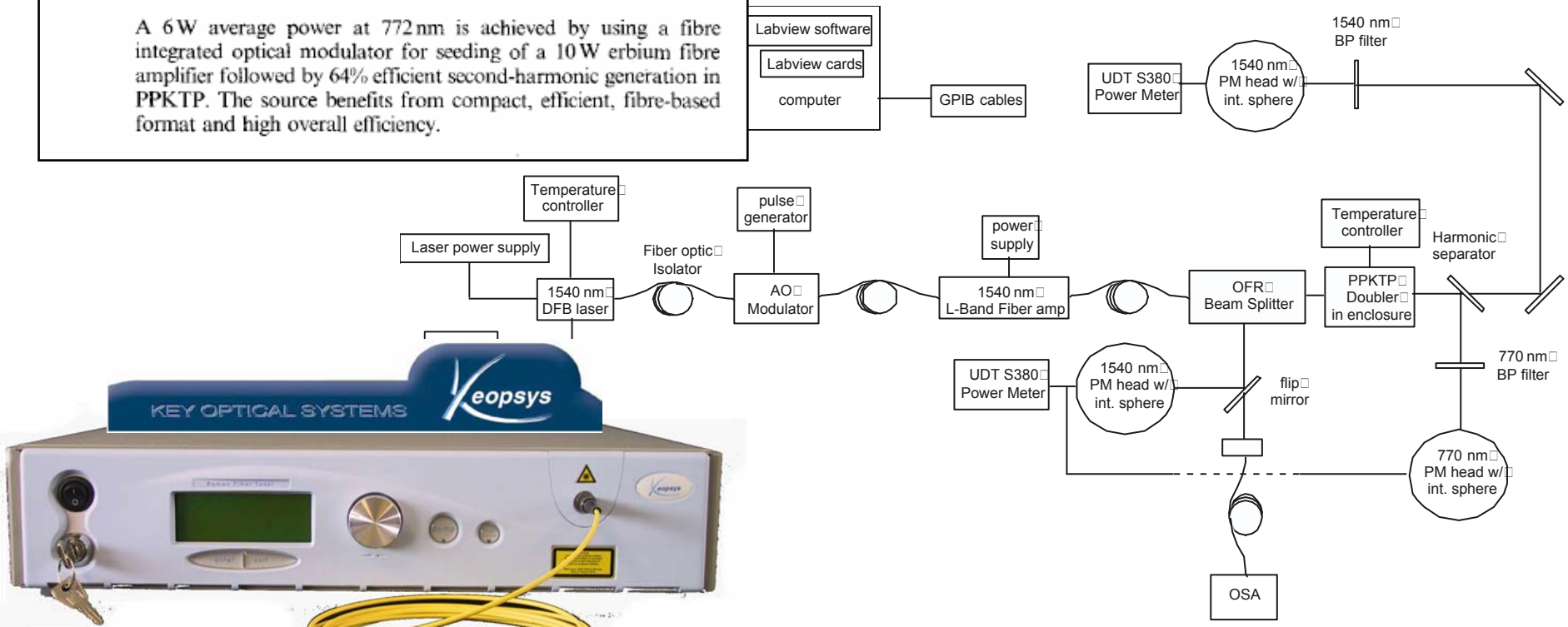
ELECTRONICS LETTERS 30th August 2001 Vol. 37 No. 18

Power scalability to 6 W of 770 nm source based on seeded fibre amplifier and PPKTP

P.A. Champert, S.V. Popov and J.R. Taylor

A 6 W average power at 772 nm is achieved by using a fibre integrated optical modulator for seeding of a 10 W erbium fibre amplifier followed by 64% efficient second-harmonic generation in PPKTP. The source benefits from compact, efficient, fibre-based format and high overall efficiency.



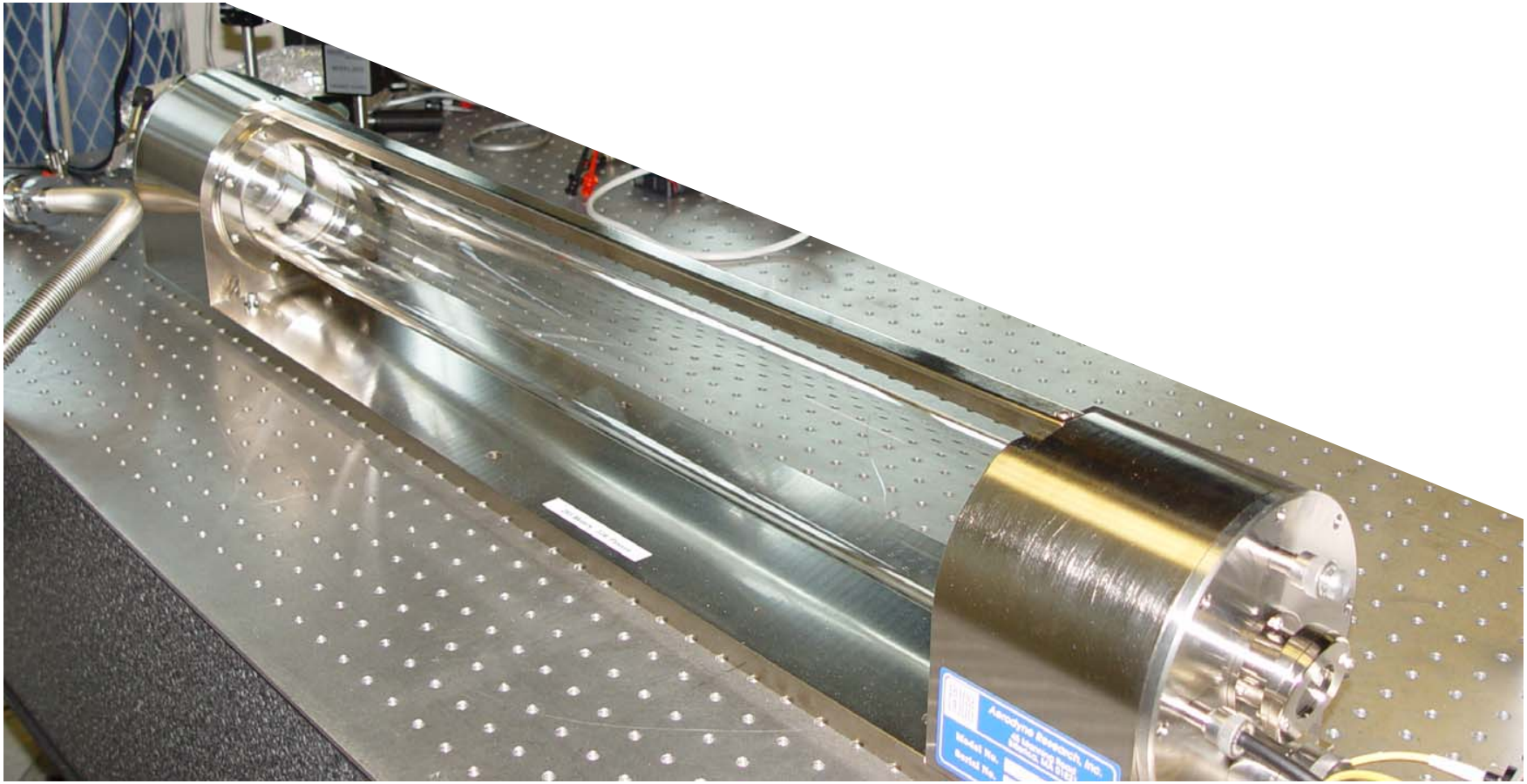


Large Mode Area fiber amplifier (Lew Goldberg)

Reference Gas Cells for calibration
Astigmatic Multipass Cells

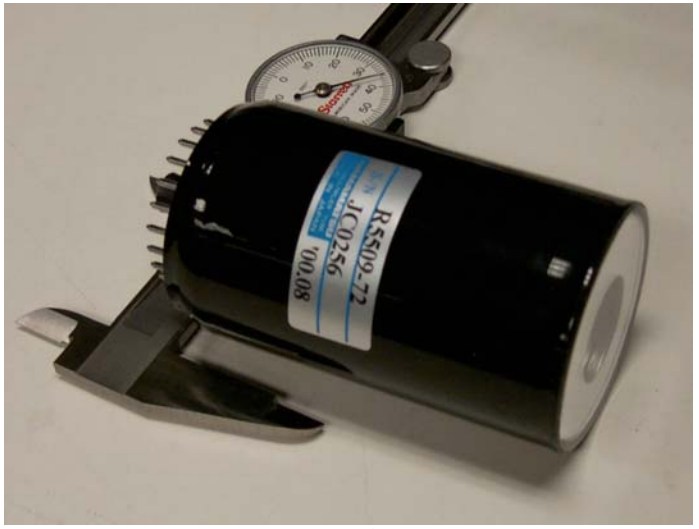
Goal:

- **Use long pathlength (~ 300 m) astigmatic multipass cell for system calibration**
- **Verify atmospheric CO2 measurements (300-400 ppm in air).**
- **Use shorter cells (10 m & 36 m) for line locking & system calibration.**

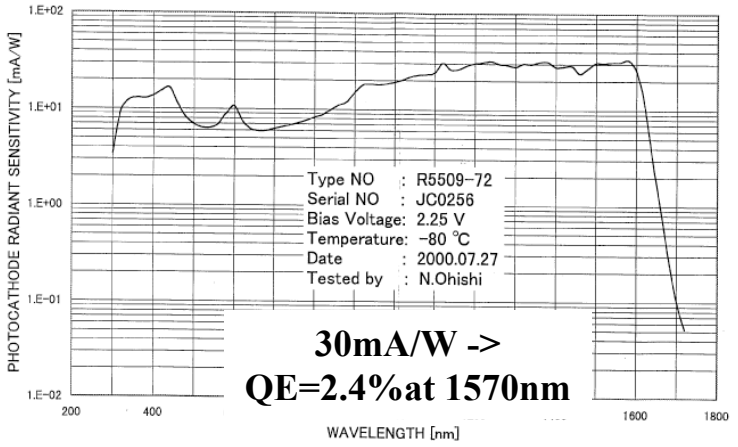


Detector: Near IR Photomultiplier Tube

- **Hamamatsu R5509-72**
- **50mm dia, 88 mm height**
- **InP/InGaAs photocathode,**
- **Quantum efficiency: 4% at 1570nm**
- **Photocathode area: 3x8 mm**
- **Gain > 1e6 at 1.5 kV**
- **Dark count rate < 150,000/s at -80 C (LN2 cooled)**
- **PMT power consumption ~150mW**
- **Can be cooled in space via TECs and passive radiator**



SPECTRAL RESPONSE CHARACTERISTIC



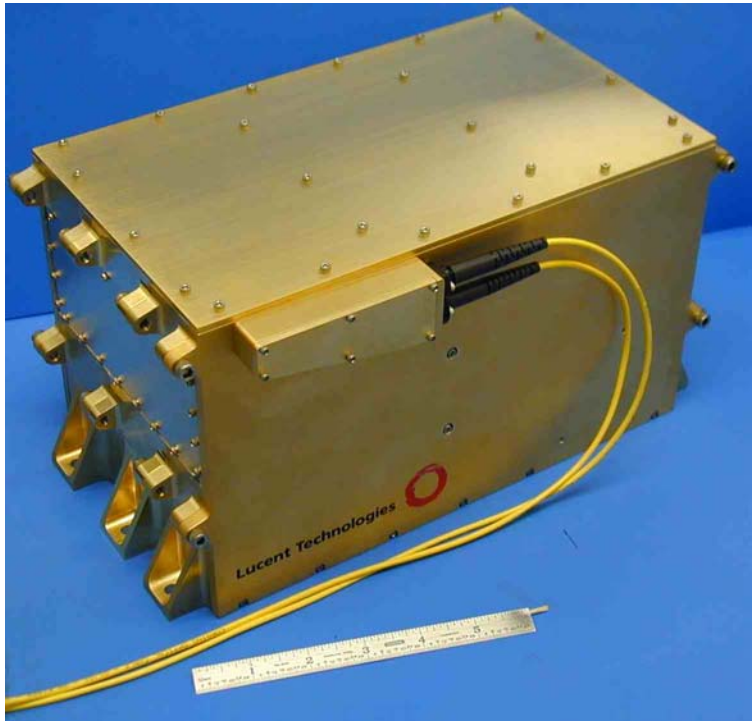
HAMAMATSU
HAMAMATSU PHOTONICS K.K., Electron Tube Center

Lucent, 3-Stage, 10W Class, Fiber Amplifier for an Airborne/Spaceflight Environment

Lucent Technologies
Bell Labs Innovations

GCL

GSFC



Specifications

- 10 watt average output power
- Typical optical input power: 0dBm to 10dBm
- Optical tuning range: 1550nm to 1565nm
- 6.3% wall-plug efficiency
- Baseplate operating temperature range: 0 ºC to 40 ºC
- Size: 0.3 ft^3
- Weight: 19 lbs
- Electrical power: 20VDC to 34VDC
- Control and telemetry via RS-422 serial interface

ADVANTAGE: Leverage large US Defense Dept. and commercial funding

Conclusions

- Laser Sounder Instrument concept provides strong optical return (compared to conventional backscatter lidar)
- Total Column Measurement Can Provide Vertical Resolution (From CO_2 Line Broadening)
- Technology approach and wavelength band selection allows leveraging of international telecom & DoD investment
- Initial results confirm great potential for laser sounder instrument
- Instrument demonstration --pathway to space flight instrument